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RGB MULTI-COLOR LED DOT-MATRIX
UNITS AND THEIR APPLICATION TO
LARGE-SIZE FLAT DISPLAYS

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Abstract A practical 16×16 RGB multi-color LED dot-matrix unit has been developed using anode-common type full-color LED lamps as pixels for the first time. This unit is compactly designed with internal driving circuitry, and it can display 7 colors (red, orange, yellow, green, blue, pink and white). A large-size RGB multi-color flat display system has also been fabricated by assembling 24 of these units. This system can display colorful moving-images by means of a personal computer. The brightness of the white color is 140 cd/m^2 , which is estimated to be sufficient for indoor display use.

1. Introduction

Among the various types of flat panel displays (i.e., CRT, VFD, PDP, LCD, LED and EL), LED displays are widely used as information boards and for transportation terminal displays due to their excellent reliability, service life and visibility.

Particularly as a result of the remarkable progress made with high-brightness red and green LEDs, multi-color LED displays that emit three different colors (red, green and amber) can now be applied outdoors.

One of the main problems with LED displays was the lack of a blue LED, because light sources for each of the three primary colors (red, green and blue) are necessary to create various color hues by mixing.

Wide band-gap semiconductors which have a more than 2.5 eV band-gap (GaN [1], [2], ZnSe/ZnS [3], [4], [5], [6], SiC [7]), have been widely studied as candidates for blue LEDs. Both p and n conduction types of SiC can be easily grown by epitaxial techniques. Therefore SiC is leading other materials in the development of practical fabrication techniques for blue LEDs.

In 1989, a practical blue LED was produced using SiC material, which is one of the $IV-IV$ compound semiconductors [7]. The luminous intensity of this blue LED is about 20 mcd at a current of 20 mA, and its intensity is sufficiently bright for use indoors. A full-color LED lamp that emits various color hues by mixing the three primary colors has also been developed [8]. This lamp consists of two

Key Words Dot-matrix unit, full-color LED lamp, LED display.

SiC blue, a GaP green and a GaP red LED chip. These developments made it possible to produce an RGB multi-color LED dot-matrix which can display colorful images. Examples of RGB multi-color LED dot-matrices that have been fabricated include a 3×7 dot array [8] and a 32×48 dot-matrix [9]. These panels, however, are not so large and cannot be electrically interconnected, preventing the fabrication of large-size RGB multi-color LED displays.

Recently, we have developed a practical 16×16 RGB multi-color LED dot-matrix unit which has internal driving circuitry and a compact design [10]. Based on this unit, we have also fabricated a large-size RGB multi-color flat display using 16×16 dot-matrix units. In this report, we describe the fabrication techniques for the dot-matrix unit, as well as the characteristics of the unit and large-size flat panel.

2. Fabrication of a new full-color LED lamp

Conventional full-color LED lamps have cathode-common electrical connections. Cathode-common type lamps need additional electric driving circuitry to convert the signal level input to the lamp. Therefore, conventional RGB multi-color LED panel systems, which use cathode-common type lamps, are large in size, and this is a problem when constructing large panels. RGB multi-color LED units must be designed compactly in order to fabricate large-size flat panels by assembling these units.

On this basis, an anode-common type full-color LED lamp has been newly developed. Figure 1 shows the structure and electrical connection of the anode-common type full-color LED lamp. Two SiC blue, a GaP green and a GaP red LED are mounted on a frame which is electrically connected to the anode terminal. Small plates, which function as electrical isolators for the GaP green and red LED, or as a heat sink for the SiC blue LEDs, are inserted between the frame and the LED. The *p*-type electrodes of those LEDs are connected to the frame,

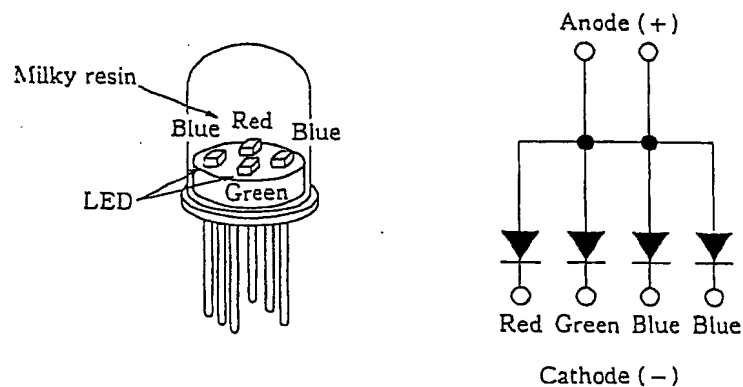


Fig. 1. Structure and electric connection of an anode-common type full-color LED lamp.

and the n -type electrodes are connected to each cathode terminal with gold wire. The anode has two terminals to simplify the arrangement of the electric circuitry. Table 1 shows the characteristics of the LEDs which are used for the anode-common type full-color LED lamp. The light output peak wavelengths are 700, 565 and 470 nm for the GaP red, GaP green and SiC blue LED chips, respectively, and the LED operating voltages are 1.9, 2.1 and 4 V, respectively. In order to mix the three primary colors, the LEDs are mounted on the frame, and covered with a milky resin which contains light-diffusive agents (SiO_2). The luminous intensity decreases with increasing amounts of light-diffusive agent. This indicates that the light-diffusive agent scatters light, and the angle of light and radiation from the lamp widens with increased scattering.

On the other hand, the light colors emitted from the lamp are poorly mixed and the primary colors are separated when there is a small amount of agent. Therefore, an agent composition of 0.5 % was selected for anode-common type full-color LED fabrication so as to satisfy two requirements: high brightness and well-mixed color. This results in a brightness level for the new full-color lamps that is 3 times higher than that of conventional lamps. Figure 2 shows the light directivity of this full-color LED lamp, whose FWHM is about 30° .

Table 1. Characteristics of LEDs used for the anode-common type full-color LED lamp

Color	Material	Peak wavelength (nm)	Operating voltage (V)
Red	GaP	700	1.9
Green	GaP	565	2.1
Blue	SiC	470	4

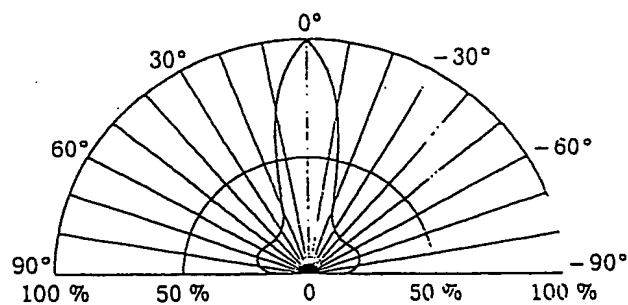


Fig. 2. Light directivity of the anode-common type full-color LED lamp.

3. Development of RGB multi-color unit

3.1 Structure This unit has 16×16 dots and consists of 16 element boards. Figure 3 shows a photograph of an element board which consists of an array of 16 full-color LED lamps and electric driving circuitry. These lamps are arranged parallel to the surface of the board and connected to its edge, as opposed to the conventional perpendicular alignment. The use of anode-common type lamps has made it possible to eliminate the signal-level conversion circuitry in the overall electric circuitry, and the circuit patterns of the 4 stacking layers are compactly designed for reduced unit depth. This has resulted in an LED unit depth of 11 cm, which is one-third less than that of the RGB multi-color LED panel fabricated in 1990 [9]. Element boards can be interconnected with precise spacing, and 16 element boards can be assembled to form a 16×16 RGB multi-color LED unit. The specifications of this unit are listed in Table 2. The dot size and pitch are $5 \text{ mm}\phi$ and 7.62 mm, respectively. The display dimensions of the unit are $122 \text{ (W)} \times 122 \text{ (H)} \times 110 \text{ mm (D)}$, including lamps.

3.2 Driving technology Figure 4 shows a schematic diagram of the electrical circuitry in a 16×16 dot RGB multi-color LED unit. The circuitry mainly consists of shift registers, EPROMs, transistors for driving the LED lamps, and variable resistors for adjusting the light output. Data for the 7 colors which can

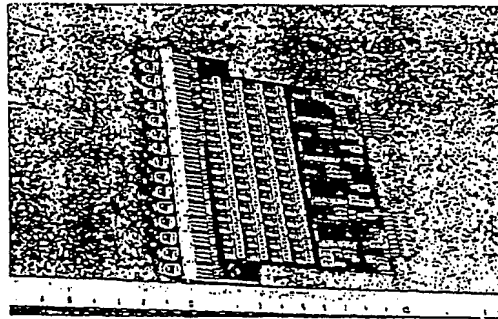


Fig. 3. Photograph of the element board.

Table 2. Specifications of a 16×16 dot RGB multi-color LED unit

Colors	7 hues (red, orange, yellow, green, blue, pink, and white)
Dot size	$5 \text{ mm}\phi$
Dot pitch	7.62 mm
Number of dots	256 (16×16) dots
Display size	$122 \times 122 \text{ mm}$

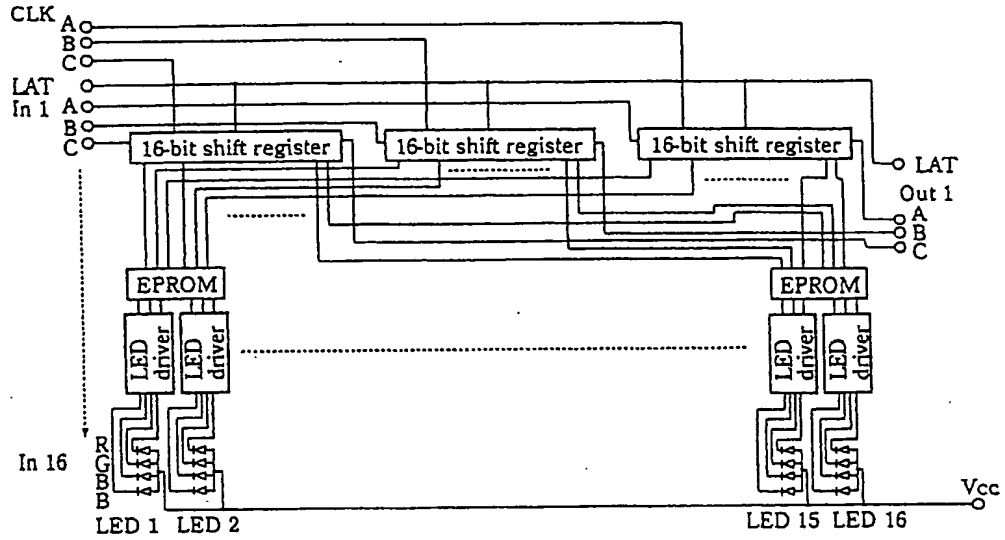


Fig. 4. Block diagram of the electrical circuitry.

be displayed by this unit are memorized in the EPROMs. Color signals are transmitted as 16 parallel data items from a personal computer to the unit and are registered at the shift-registers. This process is repeated 16 times so that the color signals for all 16×16 dots are registered. Finally, these signals are latched and a 16×16 dot color image appears on the display of the unit. Data for 7 typical colors (red, orange, yellow, green, blue, pink and white) are stored in the EPROMs. Each color is created by changing the duty ratio of the pulse currents which flow through the SiC blue, GaP green and GaP red LEDs. Table 3 shows the duty ratios of the pulse currents for each color. In the case of either blue or green, a blue or green LED is switched on continuously. For red, the duty ratio

Table 3. Duty ratios of pulse currents for 7 colors

Color	Red	Orange	Yellow	Green	Blue	Pink	White	Switch off
Red LED	4/8	4/8	2/8	—	—	8/8	1/8	—
Green LED	—	4/8	8/8	8/8	—	—	6/8	—
Blue LED 1	—	—	—	—	8/8	6/8	8/8	—
Blue LED 2	—	—	—	—	8/8	6/8	8/8	—

of the red LED is selected as one half. Other intermediate colors can also be displayed by changing the duty ratios.

3.3 Device performance Figure 5 shows the color range of light emitted by the full-color LED lamps in a CIE diagram. A full-color LED lamp can emit various colors within a triangular range whose vertices are the blue, green and red points. The 7 points indicated in the CIE diagram are the colors selected in the multi-color LED unit. The amplitudes of the pulse currents are 5, 15 and 20 mA for the red, green and blue LEDs, respectively. The brightnesses of the typical colors are listed in Table 4. When white color is displayed on the unit, the brightness is about 140 cd/m² which is 3 times higher than that of a conventional RGB multi-color LED panel [9].

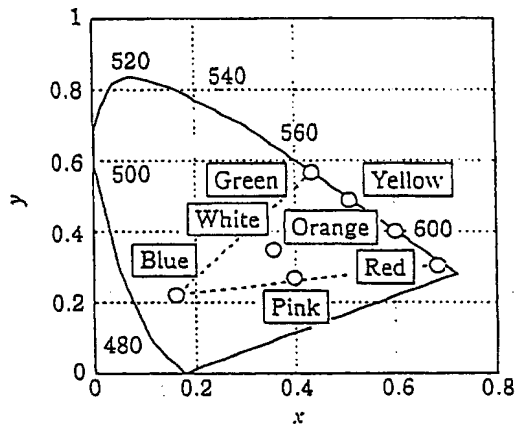


Fig. 5. Color range of light emitted by the full-color LED lamp in a CIE diagram.

Table 4. Brightness of the typical colors in the display unit

Color	Brightness (cd/m ²)	Driving current (mA/lamp)
Red	67.6	10
Green	191.4	15
Blue	33.8	40
Pink	90.5	50
White	139.1	65

4. Applications

As described in Sec. 3.2, 16×16 RGB multi-color units can be easily interconnected, so it is possible to construct large-size RGB multi-color panels by connecting units vertically and horizontally. Figure 6 shows a schematic diagram of a large-size RGB multi-color LED display system consisting of 24 units. This display consists of 4×6 units and has 6144 dots. Color image signals are transmitted from a personal computer through 96 parallel lines to unit array 1, which is located at the top of the display. Subsequently, the signals are transmitted from unit array 1 to 2, from 2 to 3, and finally from 3 to 4 through the 96 parallel cables. After the color signals that correspond to one image have been transmitted to the shift-registers in the 24 units, they are latched and an image consisting of 6144 dots is displayed. The specifications are listed in Table 5. The display's dimensions are $732 (W) \times 488 (H) \text{ mm}^2$. The total time required to display one image is less than 0.01 sec., including data-transmission and lamp-driving time. This time enables the display system to display fast-moving images

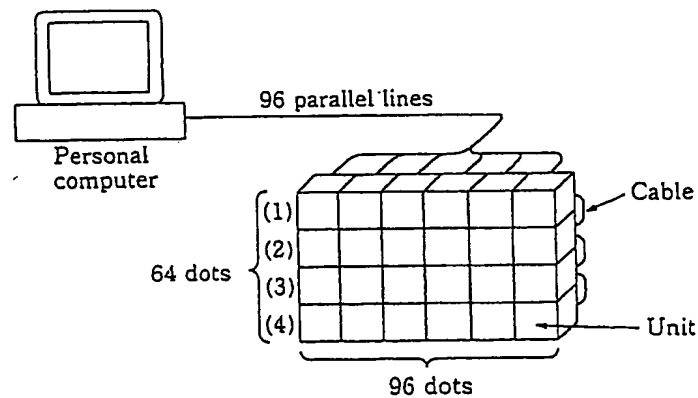


Fig. 6. Schematic diagram of a large-size RGB multi-color LED flat display system.

Table 5. Specifications of a large-size RGB multi-color flat display

Colors	7 hues (red, orange, yellow, green, blue, pink, and white)
Dot size	5 mm ϕ
Dot pitch	7.62 mm
Number of modules	24 (6 \times 4)
Number of dots	6144 (96 \times 64)
Display size	732 \times 488 mm

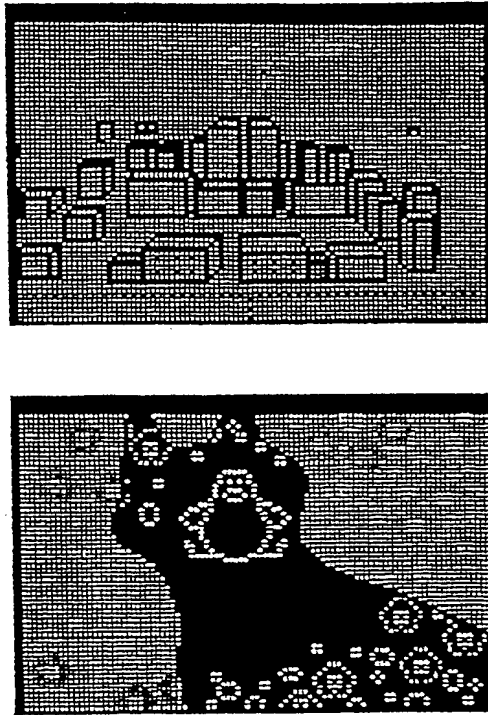


Fig. 7. Examples of images from the 96×64 RGB multi-color LED flat display.

continuously. Figure 7 shows examples of images displayed on a 96×64 RGB multi-color LED flat display.

5. Conclusion

An anode-common type full-color LED lamp has been developed and this has eliminated the need for level-conversion circuitry from the lamp-driving circuitry. An element board which includes 16×16 full-color lamps has been compactly designed. As a result, a practical 16×16 RGB multi-color LED dot-matrix unit with internal driving circuitry has been developed. This unit can display 7 different colors and can be electrically interconnected with other units. The brightness of the display's white light is about 140 cd/m^2 , which is estimated to be sufficient for indoor display use. Furthermore, a large-size RGB multi-color LED flat display has been fabricated by assembling 24 dot-matrix units. This flat display can be controlled by a personal computer and offers colorful moving-images. It is expected that these units and flat displays will be applied as indoor color information boards.

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